The efficacy and complications of posterior hemivertebra resection

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Received: 25 April 2010 / Revised: 20 December 2010 / Accepted: 28 January 2011 / Published online: 12 February 2011
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Abstract There have been several reports on hemivertebra resection via a posterior-only procedure. However, the number of reported cases is small, and various types of instrumentation have been used. In our study, we retrospectively investigated 56 consecutive cases of congenital scoliosis that were treated by posterior hemivertebra resection with transpedicular instrumentation. Radiographs were reviewed to determine the type and location of the hemivertebra, the coronal curve magnitude and the sagittal alignment pre-operatively, post-operatively and at the latest follow-up. Radiographs were also used to assess implant failure and inter-body fusion. Surgical reports and patient charts were reviewed to record any peri-operative complications. Fifty-eight posterior hemivertebrae resections from 56 patients aged 1.5–17 years with fully segmented non-incarcerated hemivertebra were evaluated. The average age at surgery was 9.9 years (1.5–17 years). The average follow-up was 32.9 months (24–58 months). The mean fusion level was 5.0 segments (2–11 segments). There was a mean improvement of 72.9% in the segmental scoliosis, from 42.4° before surgery to 12.3° at the time of the latest follow-up, and there was a mean improvement of 70% in segmental kyphosis from 42.0° to 14.5° over the same time period. The thoracic kyphosis (T5–T12) averaged 10.8° before surgery and 23.9° at the latest follow-up.

The lumbar lordosis (L1–S1) averaged -52.8° before surgery and -51.6° at the latest follow-up. Two cases with neurological claudications had complete recovery immediately after the surgery. There was one case of delayed wound healing, two fractures of the pedicle at the instrumented level, two rod breakages and one proximal junction kyphosis that required revision. There were no neurological complications. Radiolucent gaps were found in the residual space after resection on the lateral view in five cases, without any sign of implant failure or correction loss. Our results show that one-stage posterior hemivertebra resection with transpedicular instrumentation can achieve excellent correction, 360° decompression and short fusion without neurological complications. Pedicle cutting still remains a challenge in younger children when using bisegmental instrumentation. In addition, the radiolucent gaps in the residual space require further investigation.

Keywords Congenital scoliosis · Hemivertebra · Resection · Posterior surgery

Introduction

Previous studies on hemivertebra resection have focused on combined anterior and posterior procedures [1–8]. The possible advantages of combined anterior and posterior procedure may include better visualization, the less demanding nature of the technique, more complete removal of the opposite disc and better inter-body fusion than with a posterior-only procedure. With the wide application of the pedicle screws, most spine surgeries that used to be performed with combined procedures have been replaced by surgeries with a posterior-only procedure, including hemivertebra resection. In the past 9 years, more and more

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reports on posterior hemivertebra resection have emerged, and these reports draw spine surgeons' attention to the efficacy and safety of this procedure, especially in younger children [9–16]. The possible disadvantage of posterior hemivertebra resection is reduced visualization, which may lead to more retraction of the dura and nerve roots, thus increasing the risk of neurological risk and blood loss. The advantage of this procedure is that only one procedure is needed, reducing the number of incisions, the operating time and the recovery time. This retrospective study evaluated the results and related complications of posterior hemivertebra resection.

Materials and methods

We reviewed 56 consecutive patients with fully segmented non-incarcerated hemivertebra treated by posterior hemivertebra resection (Table 1). All surgeries were performed by the same surgeon between July 2002 and October 2006.

Pre-operative radiographs were reviewed to record the location of the hemivertebra, the Cobb angle and the overall sagittal and coronal alignment. Operative reports were reviewed to determine the presence of any intra-operative complications. Medical records were reviewed to identify any complications in the peri-operative and follow-up periods. Radiographs taken at the latest follow-up were reviewed to determine the curve correction, implant position, any implant failure and the presence of fusion.

There were 24 boys and 32 girls with a mean age of 9.9 years (range 1.5–17 years). The locations of the hemivertebrae were as follows: 15 thoracic (T1–T9), 34 thoracolumbar (T10–L2), 8 lumbar (L3–L4) and 1 lumbosacral (L5–S1). Forty-nine cases had a single hemivertebra, two had two hemivertebra on the same side, and five cases had one fully segmented hemivertebra and another non-segmented hemivertebra. Eleven cases had contralateral bar or rib synostosis.

Measurements were taken from standing long cassette anterior–posterior and lateral radiographs. On the coronal plane, the segmental scoliosis was measured from the upper endplate of the vertebra above the hemivertebra to the lower endplate of the vertebra below the hemivertebra, and the whole curve Cobb angle was also measured and recorded. On the sagittal plane, the segmental kyphosis was measured in the same way as was the segmental scoliosis on the coronal plane. Thoracic kyphosis (T5–T12) and lumbar lordosis (L1–S1) were also measured and recorded. Trunk shift is defined as the perpendicular distance (mm) from the sacrum center to the plumb line drawn from the midpoint of the C7 vertebra body.

Surgical technique

All patients were treated by posterior hemivertebra resection with pedicle screws. Each patient was placed in the prone position on a radiolucent operating table after administering general anesthesia. A standard midline incision was made, and sub-periosteal dissection was performed to expose the hemivertebra and the vertebrae that needed to be fused, including the lamina, transverse processes, facet joints and the surplus rib head on the convex side of the thoracic spine. Gauge 20 needles were inserted into the pedicles of the hemivertebra and the adjacent vertebrae. Fluoroscopy was used to confirm the hemivertebra (Fig. 1a), and the pedicle screws were inserted after tapping (Fig. 1b).

The posterior elements of the hemivertebra, including the lamina, upper and lower facets and the transverse process were removed to expose the pedicle and the nerve roots above and below. In the thoracic spine, the rib head and the proximal part of the surplus rib on the convex side were exposed and resected. The pleura was protected carefully. The dura was cautiously elevated posteriorly, and the epidural veins were pre-cauterized by bipolar cautery. Then the lateral cortex of the hemivertebra was exposed by blunt dissection. A pre-contoured rod was connected to the screws on the concave side before removing the vertebra body to stabilize the spine. Osteotomies were used to remove the vertebra body along the cartilage endplate. The cancellous bone was preserved for grafting. This preservation is very important for younger children because they do not have enough autogenous graft bone. We made sure that the upper and lower discs, including the cartilage endplate, were completely removed by debridement until the bleeding bone was reached. The opposite disc was removed as much as possible, but complete removal is not mandatory. Then, the endplate was adequately shaped to form a “V”-shaped space (Fig. 1c). In patients with contralateral bar and rib synostosis, the bar was cut, and the synostosed rib heads were removed.

A pre-contoured rod was then connected to the screws on the convex side. Gradual compression was applied while leaving the concave rod unlocked until the gap was closed. Anterior reconstruction with a titanium mesh cage was performed when a larger hemivertebra made the gap hard to close by compression, or two adjacent hemivertebrae were resected in the thoracic spine. This procedure could help correct the kyphosis deformity and achieve lordosis. Caution was taken to make sure that the exiting nerve roots and the dura were not impinged. If the dura was buckled severely, part of the upper and lower lamina was removed, or a mesh cage was inserted anteriorly.

Table 1 Patient characteristics

	Sex	Age (year)	Location	Implant	Fused segment	Blood loss (ml)	Op-time (min)	Follow-up (month)
1	F	13	Between T4 and T5	CDH	2	600	205	63
2	F	16	Between T8 and T9	TSRH	7	1,000	210	59
3	M	8	T12	Moss	6	400	190	55
4	F	4	L2	Moss	2	200	180	55
5	M	6	Between T12 and L1	CDH	3	200	180	53
6	M	14	Between L2 and L3	Isola	6	1,000	365	50
7	F	11	L1	Moss	3	900	210	50
8	M	15	T12	Isola + Cage	6	1,300	240	48
9	F	13	L3	Isola + Cage	4	1,200	270	45
10	F	12	L5	Moss	2	400	138	44
11	M	3	T11	USS	2	150	126	44
12	F	3	L2	USS	2	200	120	44
13	F	10	T12	Moss	2	800	180	43
14	F	11	L1	TSRH	2	400	150	43
15	F	4	Between L2 and L3	USS	3	200	120	30
16	F	14	T11	Isola + Cage	9	1,400	310	42
17	M	5	L1	CDH + Cage	4	800	240	42
18	M	3	T10	CDH	4	500	170	39
19	F	9	L1	CDH	5	1,200	180	38
20	F	13	L1	Isola	9	800	280	38
21	F	14	T10	CDH	7	1,600	210	38
22	M	14	L2	CDH + Cage	4	2,100	300	36
23	F	11	T4	CDH	4	1,100	210	38
24	M	6	T10	CDH	4	180	180	36
25	F	2	T5	USS	5	120	180	35
26	F	3.5	T9	USS	6	200	210	34
27	M	17	L2	Isola	4	1,600	215	34
28	M	3	Between T9 and T10	CDH	2	200	180	33
29	M	1.5	T11	USS	6	300	170	33
30	F	16	Between T4 and T5	CDH	4	400	210	32
31	F	13	T9	SSE	4	600	150	31
32	M	14	T10	TSRH	9	800	300	31
33	F	11	L2	CDH	5	1,200	240	31
34	M	10	T11	CDH + Cage	8	1,100	210	31
35	M	6	Between L3 and L4	CDH	5	800	260	30
36	M	14	Between T11 and T12	CDH + Cage	5	1,050	255	28
37	F	9	T8 and T10	CDH	10	1,300	270	28
38	F	6	Between L2 and L3	SSE	8	1,500	300	27
39	F	10	Between L3 and L4	CDH	2	500	120	26
40	M	15	T12	Isola	10	1,400	240	25
41	F	17	L4	CDH	4	1,600	330	24
42	M	6	Between T12 and L1	Moss + Cage	4	800	180	21
43	F	16	T10	Isola + Monarch + Cage	9	1,200	210	21
44	M	14	L1	Isola + Monarch	7	1,700	210	20
45	F	17	T8	Isola + Monarch	7	800	180	20
46	M	14	T9	CDH	9	1,200	205	20
47	F	10	Between T10 and T11	CDH + Cage	4	800	225	20
48	M	3	Between L1 and L2	USS	3	120	160	18

Table 1 continued

	Sex	Age (year)	Location	Implant	Fused segment	Blood loss (ml)	Op-time (min)	Follow-up (month)
49	F	4	Between T12 and L1	CDH	3	500	155	18
50	F	6	L3	CDH + Cage	2	300	210	17
51	M	2.5	Between L1 and L2	USS	3	200	180	16
52	F	36	T11	Isola + Monarch + Cage	11	1,755	290	15
53	M	8	T4	CDH	4	800	210	14
54	M	3	Between T7 and T8, T11 and T12	CDH	2 + 2	800	150	14
55	F	9	Between T9 and T10	Moss	4	300	175	12
56	F	7	T8	CDH	8	900	220	8
Average		9.9			5.0	812.1	210.1	32.9

Fig. 1 Fluoroscopy was used to confirm the right levels (a); the pedicle screws were placed after tapping (b). The hemivertebra with the disc above and below were removed completely (c). The gap left

after the resection was closed by the compression and the postero-lateral fusion was performed (d)

Decortication of the posterior elements was performed after the correction. Autogenous bone from the hemivertebra was used for the posterolateral fusion (Fig. 1d).

Bisegmental fusion was indicated for single hemivertebra with mild curvature (scoliosis and kyphosis $<40^\circ$). If there is a long structural curve or the segmental kyphosis was $>40^\circ$, longer instrumentation and fusion is recommended.

Sensory- and motor-evoked potentials were used intra-operatively.

When the patient started to walk after surgery, a two-piece plastic brace was used for 3–6 months.

Results

A total of 58 hemivertebrae were resected in 56 patients. The average follow-up time was 32.9 months (24–58 months). The mean fusion level was 5.0 segments (2–11 segments). The average operation time was 210.1 min (120–365 min), and the average intra-operative blood loss was 812.1 ml (150–2,100 ml).

General correction results

The correction in the coronal and sagittal planes are presented in Tables 2 and 3. There was a 72.9% scoliosis correction with a 0.8° loss of correction on the coronal plane. The trunk shift underwent progressive improvement during the follow-up period. On the sagittal plane, the correction rate was 70.0%, and a 1.9° loss was noted.

Correction results of bisegmental instrumentation and fusion

Bisegmental fusion was performed in 11 cases with an average age of 4.5 years (2–13 years), 6 cases of whom were younger than 6 years old. The location of the hemivertebra was from T7 to L5.

The results are presented in Tables 2 and 3. The correction rate of segmental scoliosis was 86.6%, with a loss of 1° at the latest follow-up. There was an improvement of 84.7% in the segmental kyphosis, and the correction loss at the latest follow-up was 1.2° .

Table 2 Correction of the coronal plane

	Whole scoliosis			Segmental scoliosis			Trunk shift		
	Pre-op	Post-op	Follow-up	Pre-op	Post-op	Follow-up	Pre-op	Post-op	Follow-up
1	40	9	10	40	9	10	15	9	6
2	66	37	33	52	32	30	20	6	9
3	25	6	5	25	6	5	16	0	0
4	32	4	1	32	4	1	5	21	4
5	30	3	8	20	0	3	13	8	0
6	54	12	13	43	23	17	12	21	30
7	30	10	23	24	8	15	29	38	42
8	100	20	25	100	20	25	15	14	12
9	35	17	17	35	17	17	10	4	5
10	27	9	10	27	9	10	14	6	2
11	40	10	13	40	10	13	10	7	5
12	33	0	4	33	0	4	8	3	3
13	39	3	4	39	3	4	16	10	7
14	15	0	0	30	0	0	0	0	0
15	42	3	0	33	3	2	13	8	0
16	52	44	43	52	44	43	5	0	0
17	44	16	13	42	14	12	14	17	6
18	29	0	0	29	0	0	3	3	9
19	55	10	22	55	10	22	31	22	3
20	70	36	40	52	30	33	16	20	7
21	56	13	16	56	13	16	16	28	0
22	43	8	12	43	8	12	18	7	7
23	37	16	22	35	13	12	5	16	8
24	55	33	35	43	23	30	7	11	15
25	44	14	11	32	0	0	8	2	2
26	61	22	28	40	8	10	5	2	4
27	45	3	3	45	3	3	10	15	3
28	40	10	8	39	8	8	20	0	0
29	62	11	17	32	18	14	5	17	2
30	57	22	33	13	7	8	25	15	3
31	50	18	15	50	18	15	7	21	6
32	63	23	22	63	23	22	33	20	12
33	60	15	12	48	16	15	17	65	10
34	50	3	1	40	2	1	0	9	10
35	54	13	15	27	5	7	40	7	24
36	45	9	8	50	15	16	8	0	0
37	65	10	8	62	15	10	12	35	7
38	52	2	4	52	2	4	24	6	5
39	41	8	15	35	6	10	8	20	12
40	98	29	27	50	16	20	24	50	23
41	42	14	17	40	8	12	53	40	22
42	50	3	7	43	3	5	20	0	3
43	55	5	2	42	2	2	15	7	3
44	93	33	30	100	43	41	14	13	4
45	25	7	7	25	7	7	8	4	0
46	65	25	27	55	30	30	32	44	11
47	44	6	12	44	6	12	17	21	8

Table 2 continued

	Whole scoliosis			Segmental scoliosis			Trunk shift		
	Pre-op	Post-op	Follow-up	Pre-op	Post-op	Follow-up	Pre-op	Post-op	Follow-up
48	25	0	1	25	0	1	8	18	20
49	43	3	2	43	3	2	2	13	0
50	40	5	5	40	5	5	12	11	0
51	50	18	21	50	18	21	12	12	5
52	47	14	18	47	14	18	60	40	34
53	40	2	2	40	2	2	23	7	8
54	48	0	0	48	0	0	36	10	9
55	39	20	20	39	20	20	30	20	17
56	62	25	20	48	22	13	9	4	2
Average	48.3	12.7	14.1	42.4	11.5	12.3	16.2	14.8	8.0

Results of patients with neurological claudication

There were two cases with neurological claudication and dysfunction of the bladder due to severe kyphoscoliosis caused by T11 and T12 hemivertebrae. Myelography showed complete contrast interruption at the thoracolumbar junction. All symptoms disappeared immediately after surgery, and post-operative myelography showed complete decompression (Figs. 2, 3).

Complications

There were two pedicle fractures. Both were found in bisegmental fusion cases in younger patients, and revision surgeries were performed. Two cases developed rod breakages. One was discovered 6 months after surgery, and revision surgery was not completed because solid fusion was observed. No rod migration or correction loss was noted in the following observation. The other breakage was found 2 years after surgery, with rod migration and correction loss. Pseudarthrosis was detected during the revision surgery, and rod change with additional inter-body fusion with a mesh cage at the same level was applied. Both of the above two cases were treated with titanium rods with a diameter of 4.5 mm. Proximal junctional kyphosis was found in one case with a thoracic and thoracolumbar curve at the 36-month follow-up evaluation. Original hemivertebra resection and fusion was performed in the lower curve, and revision surgery was performed to extend the fusion to the thoracic curve. Despite the aut cancellous bone grafting in the inter-body space after hemivertebra resection before convex compression, radiolucent gaps were still found on the lateral view in five cases, without any sign of implant failure or correction loss (Fig. 4). One case with severe kyphoscoliosis developed delayed wound union, and debridement was needed. The wound healed 3 weeks after surgery.

Discussion

Fully segmented non-incarcerated hemivertebrae have normal growth plates, leading to increasing deformities during further growth, followed by many secondary changes. As delayed treatment requires longer fusion with a higher risk of neurological compromise, such deformities usually require early surgical intervention to achieve control or correction of the local malformations; and with early intervention, secondary changes can be avoided. In the past several decades, many types of procedures have been introduced, including combined anterior and posterior epiphysiodesis, combined anterior and posterior epiphysiodesis with concave distraction, hemivertebra osteotomy by the egg-shell technique, hemivertebra resection by a combined anterior and posterior approach and hemivertebra resection with a posterior-only approach. Theoretically, hemivertebra resection can remove the pathology and correct the deformity completely; thus, it is the primary method to treat this kind of deformity. However, it is a highly demanding technique and may cause neurological complications. Combined anterior and posterior hemivertebra resection can offer a good visualization of neural structures and is less demanding; thus, most surgeons start hemivertebra resection using this procedure.

The reported scoliosis correction rate of anterior and posterior hemivertebra resection averages 35.2–71.1% [1–8]. The common neurological complications were transient muscle weakness of the lower limb, with a rate of 9.1–20.5% [7, 15]. Holt et al. [15] reported 7 (39) cases with transient muscle weakness and one (39) case with permanent nerve root injury. Lazar et al. [7] found one (11) such case, and King also reported one (7) case with this complication. Because two incisions are needed, complications related to the anterior procedure were also reported. Bollini et al. [2] reported that 3 cases among their 34 cases experienced anterior approach-related complications, one

Table 3 Correction of the sagittal plane

	Segmental kyphosis			Thoracic kyphosis			Lumbar lordosis		
	Pre-op	Post-op	Follow-up	Pre-op	Post-op	Follow-up	Pre-op	Post-op	Follow-up
1	34	14	18	9	5	20	−50	−42	−46
2	25	19	18	25	28	33	−48	−40	−60
3	56	33	33	16	18	12	−13	−20	−23
4	31	5	3	7	21	15	−27	−41	−52
5	19	−4	−6	−5	18	14	−36	−36	−40
6	27	−3	−3	27	28	57	−22	−45	−48
7	32	10	15	12	28	29	−57	−35	−51
8	110	10	27	−7	40	80	−105	−55	−68
9	65	17	25	−5	10	7	−20	−36	−28
10	10	0	1	17	15	15	−51	−58	−50
11	30	16	25	42	32	45	−58	−59	−80
12	14	3	0	5	18	12	−9	−20	−42
13	39	13	15	24	28	20	−55	−44	−45
14	35	5	10	25	28	21	−63	−60	−48
15	10	−1	0	10	16	18	−46	−42	−45
16	80	49	45	−11	15	12	−91	−68	−63
17	61	5	19	−10	13	23	−73	−43	−57
18	26	5	12	30	27	37	−58	−55	−55
19	20	4	8	14	27	27	−50	−43	−48
20	67	34	37	−7	7	15	−53	−58	−57
21	32	9	11	37	30	28	−52	−52	−41
22	50	38	35	−5	15	7	−31	−35	−32
23	19	7	9	35	23	36	−56	−35	−50
24	65	36	36	53	38	40	−67	−53	−68
25	15	9	6	22	15	20	−60	−55	−53
26	17	2	5	−5	3	19	−35	−25	−50
27	56	−3	1	−3	18	15	−50	−42	−40
28	27	4	2	18	20	29	−60	−36	−72
29	27	13	11	−4	5	12	−42	−25	−30
30	25	−15	−10	3	18	30	−11	−33	−38
31	30	20	23	19	16	20	−49	−43	−43
32	69	36	29	−10	0	5	−70	−55	−52
33	37	7	2	−2	11	15	−23	−42	−43
34	78	31	27	15	35	43	−102	−70	−82
35	25	7	2	4	8	16	−33	−43	−40
36	73	17	20	−3	16	30	−80	−62	−63
37	73	25	30	52	30	37	−58	−53	−60
38	85	18	22	−14	12	18	−75	−63	−60
39	10	−12	−15	16	18	20	−56	−53	−62
40	78	30	28	−9	12	10	−56	−45	−48
41	14	−14	−10	2	17	12	−30	−35	−38
42	45	7	23	2	28	25	−70	−37	−60
43	77	30	26	16	10	15	−101	−62	−60
44	100	50	45	−13	26	24	−78	−63	−72
45	21	5	4	25	23	23	−36	−42	−42
46	65	13	15	43	16	23	−58	−53	−55
47	57	23	17	0	17	36	−93	−52	−63

Table 3 continued

	Segmental kyphosis			Thoracic kyphosis			Lumbar lordosis		
	Pre-op	Post-op	Follow-up	Pre-op	Post-op	Follow-up	Pre-op	Post-op	Follow-up
48	28	5	10	22	15	15	−30	−38	−50
49	22	4	9	11	25	33	−51	−40	−53
50	13	−6	−2	2	8	8	−28	−47	−40
51	33	0	5	−10	22	18	−8	−44	−43
52	79	25	20	−38	0	5	−77	−53	−50
53	27	12	21	12	15	33	−62	−35	−48
54	37	0	6	45	40	48	−80	−57	−63
55	20	15	23	26	27	35	−63	−46	−70
56	33	26	32	22	20	21	−40	−37	−52
Average	42.0	12.6	14.5	10.8	19.2	23.9	−52.8	−45.7	−51.6

Fig. 2 A 13-year-old female patient with T11 hemivertebra, presenting severe kyphoscoliosis, which cause compression to the spinal cord as the pre-operative CTM and myelography showed. The

thorough decompression offered by the posterior hemivertebra resection could be noted on the post-operative myelography

with a pneumothorax, one with pleural effusion requiring drainage, and one with an abdominal hernia.

Shono et al. [13] reported on hemivertebra resection through a single posterior approach with a mean correction rate of 63.3% in 12 patients. Nakamura et al. [9] reported five cases of posterior hemivertebra resection with an improvement of 55.1% for three thoracolumbar hemivertebrae, 31.4% for two lumbosacral hemivertebrae on the coronal plane and 67.4% for regional kyphosis. One loosening of the internal fixation was reported in this series.

Ruf and Harms [10] reported hemivertebra resection by the posterior-only procedure. They reported 21 cases with an improvement of 63.4% on the coronal plane. In 2003, they reported 28 cases younger than 6 years old with a mean follow-up time of 3.5 years. Pedicle screws were used, and the mean correction rate of the scoliosis was 71.1% (from 45° to 13°). Complications included two pedicle fractures, three instrumentation failures, two additional surgeries for curve progression and one infection [12]. In 2009, they reported 41 cases younger than 6 years old with a mean

Fig. 3 A 3-year-old boy with T10–T11 hemivertebra, postoperative radiograph showed fracture of the pedicle at the instrumented level. Revision surgery was performed to extend fusion one level below and above, 4-year follow-up showed a good correction

follow-up of 6 years and 2 months. In patients without bar formation, there was a correction rate of 80.5% of the main curve and 63.6% of the kyphosis. In patients with bar formation, the improvement of the main curve was 66.7%, and the kyphosis improvement was 62.5%. The complications included three implant failures, three convex pedicle breakages and two progressed deformities after the surgery. Revision surgeries were performed on these cases [16]. Hedequist et al. [14] reported a group of 10 patients younger than 8 years old; they performed bisegmental transpedicular instrumentation with additional laminar hooks to strengthen the fixation. They achieved a mean correction of 80% of the scoliosis without instrumentation-related complications. One case had post-operative EHL

weakness and recovered 4 weeks after surgery. In the current study, the correction rates of segmental scoliosis and kyphosis were 72.9 and 70.0%, respectively, and in the bisegmental instrumentation group, the correction rates were 86.6 and 84.7%, respectively, which showed a tendency of better correction and shorter fusion when earlier surgical intervention was performed.

Therefore, we can conclude from the literature and our studies that the posterior-only procedure tends to offer a better correction with a lower risk of neurological compromise than the combined procedures. The reason for these results might be the better visualization of the spinal cord or nerve root during the whole procedure and the easier detection of compression on the neural structures.

Fig. 4 A 35-month-old girl with L2 hemivertebra, radiolucent gap was still clear on the lateral view at 3 years follow-up, but there was no correction loss or failure of instrumentation

Additionally, the posterior-only procedure requires one fewer incision and decreased the number of anterior approach-related complications.

The biggest challenge still remains in short or bisegmental fusion with transpedicular instrumentation after posterior hemivertebra resection in very young patients. Fractures of the pedicle at the instrumented level are the most common complications. Except for technical error and improper instrumentation, softer bone cortex and smaller pedicle diameter are the main causes of failure. Ruf et al. [16] reported three pedicle fractures (7.3%) and three instrumentation failures (7.3%). In our series, both of the pedicle fractures at the instrumented levels that required revision (3.6%) occurred in the bisegmental fusion group in patients younger than 6 years old. One revision surgery for two rod breakages (3.6%) called into question the ability of rods with a small diameter (ϕ 4.5 mm) to maintain the initial stability of the spine after hemivertebra resection. Hedequist [14] reported no instrumentation failures when using a three-rod technique, but implant bulging may be potential risk to the skin. To prevent this problem, we should remove the hemivertebra, annulus and cartilage completely; prepare the pedicle tunnel delicately by fluoroscopy; and choose a proper diameter screw by analyzing CT scans. If the gap left after resection of a large hemivertebra is hard to close, anterior reconstruction should be performed to decrease the stress on the screws. Bisegmental instrumentation is not indicated for thoracic hemivertebra because the thoracic cage can provide extra resistance and cause more failures. It is safer to remove the rib head at the same time and to extend the fusion one more level above and below.

In our series, CT scanning with three-dimensional reconstructions was performed for every case to acquire

detailed information. The three-dimensional reconstructions provided detailed knowledge of the anterior and posterior components of the malformed vertebrae and the relationships with adjacent vertebrae. It helps a lot to define the anatomy of the hemivertebra and its adjacent vertebra. Furthermore, we performed CT scans for each pedicle to be instrumented. Measurements of pedicle size by axial scanning and sagittal reconstruction could help in choosing pedicle screws with the proper diameter and length.

In this study, we noted that five cases (9%) had radiolucent gaps at the resection site on the lateral view of radiographs without implant failure or correction loss. These gaps may be due to the incomplete removal of the cartilage endplate or to the absorption of the bone graft. As the post-lateral fusion was performed after the resection and compression, the radiolucent gap did not lead to correction loss. Further investigation with CT scanning and sagittal reconstruction is required to analyze this phenomenon.

Conclusion

One-stage posterior hemivertebra resection with transpedicular instrumentation can offer excellent correction and 360° decompression without neurological complications. Short segmental fusion can be performed effectively and safely on very young children with moderate and mild deformity, saving motion segments. Thus, it is an ideal procedure for very young children. To date, the results for this series of patients are excellent, with very little loss of correction at follow-up. However, the follow-up duration is short when considering that some patients were younger

than 6 years old and are far from the end of growth. Late loss of correction or implant migration is still possible. Fracture of the pedicle at the instrumented level still remains a challenge in very young children with bisegmental fusion. The reason for radiolucent gaps in the residual space after hemivertebra resection is not clear and remains to be further investigated.

Conflict of interest None of the authors has any potential conflict of interest.

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